

WE CLAIM:

1. A thermal switch, comprising:
a heat source;
5 a heat sink; and
at least one liquid-metal droplet disposed between the heat source and the heat sink,
the droplet being configured to conduct heat from the heat source to the heat sink whenever
the droplet is thermally coupled to the heat source and the heat sink.
- 10 2. The thermal switch of claim 1, wherein the droplet comprises mercury.
3. The thermal switch of claim 1, wherein the droplet is about 10 microns to
about 1000 microns in diameter.
- 15 4. The thermal switch of claim 1, wherein at least one of the heat source and
the heat sink comprises a micro-transducer.
5. The thermal switch of claim 1, wherein:
the heat source comprises a first micro-transducer and the heat sink comprises a
20 second micro-transducer; and
the droplet transfers heat from the first micro-transducer to the second micro-
transducer whenever the droplet is thermally coupled to the first micro-transducer and to the
second micro-transducer.
- 25 6. The thermal switch of claim 5, wherein:
the droplet is in constant thermal contact with the first micro-transducer; and
the second micro-transducer comprises a deflectable member that deflects between
a deflected position and a non-deflected position, wherein whenever the deflectable member
is in the deflected position, the deflectable member contacts the droplet to allow heat to be
30 conducted from the first micro-transducer to the second micro-transducer via the droplet,
and whenever the deflectable member is in the non-deflected position, the deflectable
member is spaced from the droplet to prevent heat from being conducted from the first
micro-transducer to the second micro-transducer via the droplet.

7. The thermal switch of claim 5, wherein:

the first micro-transducer comprises a first micro-heat engine and the second micro-transducer comprises a second micro-heat engine; and

heat from the first micro-heat engine is transferred to the second micro-heat engine
5 whenever the droplet is thermally coupled to the first and second micro-heat engines.

8. The thermal switch of claim 7, wherein the first and second micro-heat engines are operable to convert heat energy into electrical energy.

10 9. The thermal switch of claim 5, wherein:

the first micro-transducer comprises a first micro-heat pump and the second micro-transducer comprises a second micro-heat pump; and

heat rejected by the first micro-heat pump is transferred to the second micro-heat pump whenever the droplet is thermally coupled to the first and second micro-heat pumps.

15 10. The thermal switch of claim 1, wherein:

the droplet is in constant thermal contact with one of the heat sink and the heat source; and

the other of the heat sink and the heat source comprises an actuator that selectively
20 thermally contacts the droplet.

11. The thermal switch of claim 10, wherein the actuator comprises a flexible member that is selectively deflectable between a deflected position in which the flexible member contacts the droplet and a non-deflected position in which the flexible member is
25 spaced from the droplet.

12. The thermal switch of claim 11, wherein the flexible member comprises a piezoelectric transducer that deflects and contacts the droplet upon application of a voltage to the piezoelectric transducer.

30 13. The thermal switch of claim 11, wherein the flexible member is an electrostatic transducer that deflects and contacts the droplet upon application of a voltage to the thermal switch.

14. A thermal switch for transferring heat into or away from a body comprising at least one drop of liquid metal that transfers heat into or away from the body whenever the body is thermally coupled to the drop.

5 15. The thermal switch of claim 14, further comprising an actuator that selectively thermally couples together the drop and the body.

16. The thermal switch of claim 14, further comprising:
a first thermally conductive member; and
10 a second thermally conductive member; wherein
the drop is disposed on the first thermally conductive member, and the second thermally conductive member is movable between a first position and a second position,
whenever the second thermally conductive member is in the first position, it
contacts the drop, thereby allowing heat to be transferred into or away from the body
15 through the thermal switch, and
whenever the second thermally conductive member is in the second position, it is spaced from the drop to minimize the transfer of heat into or away from the body through the thermal switch.

20 17. The thermal switch of claim 16, wherein the second thermally conductive member is a deflectable member that is operable selectively to deflect toward and away from the first thermally conductive member such that, whenever the deflectable member deflects toward the first thermally conductive member, the deflectable member contacts the drop, and whenever the deflectable member deflects away from the first thermally
25 conductive member, the deflectable member becomes spaced from the drop.

18. The thermal switch of claim 17, wherein:
the first thermally conductive member comprises at least one electrode; and
the second thermally conductive member comprises at least one electrode;
30 wherein application of a voltage to the electrodes generates an electrostatic charge that causes the second thermally conductive member to deflect toward the first thermally conductive member.

19. The thermal switch of claim 17, wherein:
the first and second thermally conductive members cooperatively form a fluid-tight
cavity therebetween; and
an insulating gas is contained in the cavity.
- 5 20. The thermal switch of claim 19, wherein the insulating gas is argon.
21. The thermal switch of claim 14, wherein the body is a micro-transducer.
- 10 22. The thermal switch of claim 14, further comprising a plurality of thermal
switch elements, each thermal switch element comprising at least one drop of liquid metal
and being independently operable to switch between an on position to establish a high
thermally conductive path that facilitates heat transfer into or away from the body and an off
position to establish a low thermally conductive path that reduces heat transfer into or away
15 from the body.
23. The thermal switch of claim 14, wherein the body is a thermoelectric
cooler.
- 20 24. The thermal switch of claim 14, wherein the body is a thermal cycler.
25. A thermal switch for controlling the flow of heat into or away from a body,
comprising:
a drop of a thermally conductive liquid; and
25 an activation element that is selectively movable between a first position to activate
the thermal switch and allow heat to flow into or away from the body through the drop, and
a second position to de-activate the thermal switch to reduce the flow of heat into or away
from the body through the drop.
- 30 26. The thermal switch of claim 25, wherein the liquid is a metal.
27. The thermal switch of claim 25, wherein the drop is disposed on a metal
contact.

28. A thermal switch assembly, comprising:
a first major layer;
a second major layer; and
a plurality of thermal switch elements cooperatively formed between the first and
5 second switch elements, each thermal switch element being selectively and independently
operable relative to each other to increase and decrease the transfer of heat between the first
and second major layers.

29. The thermal switch assembly of claim 28, wherein the thermal switch
10 elements comprise an array of thermal switch elements formed by the first and second major
layers.

30. The thermal switch assembly of claim 28, wherein each thermal switch
element comprises a drop of a thermally conductive liquid disposed between the first and
15 second major layers.

31. The thermal switch assembly of claim 30, wherein each thermal switch
comprises a flexible membrane formed in the first major layer that is selectively deflectable
between a deflected position in which the membrane contacts a respective drop and a non-
20 deflected position in which the membrane is spaced from the respective drop.

32. The thermal switch assembly of claim 31, wherein each thermal switch
comprises at least one first electrode mounted on a respective flexible membrane and at least
one second electrode mounted on the second major layer, wherein, whenever a voltage is
25 applied to the first and second electrodes of one of the thermal switches, the respective
flexible membrane is caused to deflect and contact a respective drop.

33. A method for controlling the transfer of heat from a heat source to a heat
sink, the method comprising:
30 thermally coupling the heat source to the heat sink via a drop of a thermally
conductive liquid; and
conducting heat from heat source to the heat sink through the drop.

34. The method of claim 33, wherein thermally coupling the heat source to the
35 heat sink comprises contacting the drop with the heat source and the heat sink.

35. The method of claim 33, further comprising preventing conduction of heat from the heat source to the heat sink via the drop by creating a gap between the drop and one of the heat source and the heat sink.

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36. The method of claim 33, wherein the liquid is a metal.

37. The method of claim 33, wherein:

the heat source comprises a low-temperature heat source of a thermoelectric cooler
10 and the heat sink comprises a high-temperature heat sink of a thermoelectric cooler; and
the method further comprises selectively thermally coupling the low-temperature heat source to the thermoelectric cooler via the drop to allow the thermoelectric cooler to absorb heat from the low-temperature heat source and pass heat to the high-temperature heat sink.

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38. The method of claim 33, wherein:

the heat source is a first micro-transducer and the heat sink is a second micro-transducer; and

the method comprises selectively thermally coupling the first micro-transducer to
20 the second micro-transducer to allow heat to be transferred from the first micro-transducer to the second micro-transducer through the drop.

39. A method for transferring heat from a heat source to a heat sink via a thermal switch comprising a liquid-metal drop, the method comprising activating the
25 thermal switch to establish a low-thermal-resistance path between the heat source and the heat sink via the liquid-metal drop to cause heat to be conducted from the heat source to the heat sink through the liquid-metal drop.

40. The method of claim 39, further comprising de-activating the thermal
30 switch to establish a high-thermal-resistance path between the heat source and the heat sink to reduce or prevent heat from flowing from the heat source to the heat sink through the thermal switch.

41. A thermoelectric cooler, comprising:
35 a low-temperature heat source;

a high-temperature heat sink;
a thermoelectric element thermally coupled to the high-temperature heat sink; and
a thermal switch comprising at least one drop of a thermally conductive liquid, the
thermal switch being configured to couple the low-temperature heat source to the
5 thermoelectric element.

42. A thermal cyclor, comprising:
a tube-support device that supports one or more containers each configured to
contain a sample to be processed by the thermal cyclor;
10 a heat source configured to supply heat to the samples in the containers;
a cold source configured to supply cold to the samples in the containers; and
at least one thermal switch configured to selectively thermally couple at least one of
the heat source and cold source to the containers.

15 43. A thermal switch, comprising:
a body defining a fluid-tight cavity having first and second major surfaces;
a working fluid contained in the cavity, wherein the cavity is operable as a heat pipe
to cause the working fluid to transfer latent heat from the first major surface to the second
major surface;
20 a flexible membrane forming the first major surface of the cavity, the membrane
being deflectable inwardly toward the second major surface of the cavity; and
at least one wick formed on the membrane and positioned to absorb working fluid
that has condensed on the second major surface whenever the membrane is deflected
inwardly toward the second major surface.

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